downpour of rain, 1 inch falling in 35 minutes between 12:10 p. m. and 12:45 p. m.

Fig. 1 is a rough plan of a small section of the city of Burlington, and shows the streets, buildings, and stores mentioned by the eyewitnesses; this section is nearly a mile west-northwest of the local office of the Weather Bureau.

STUDIES ON THE PHENOMENA OF THE EVAPORATION OF WATER OVER LAKES AND RESERVOIRS.

By PROF. FRANK H. BIGELOW. Dated June 20, 1907.

I—THE PROPOSED STUDY ON THE PROBLEMS OF EVAPORATION AT THE SALTON SEA, SOUTHERN CALIFORNIA.

The Salton Sea in May, 1907, consisted of a sheet of fresh water, 45 miles long and about 10 or 15 miles wide, containing 440 square miles of surface area, 205 feet below the mean tide level of the Pacific Ocean. This body of water has recently been formed by overflow from the Colorado River and has been protected from further inflow; it will probably dry out in ten or twelve years, so that an unusually fine example of evaporation on a large scale in that arid climate is offered for study. Mr. G. K. Gilbert, of the U. S. Geological Survey, proposed that a preliminary examination be made of the shores of the lake, to see whether the surface inflow and underground seepage can be measured. Subsequently, after several conferences between the representatives of the U. S. Geological Survey, the U. S. Reclamation Service, and the U. S. Weather Bureau, a Board of Conference was sent to the Salton Basin in May, to examine in detail the feasibility of undertaking a campaign on evaporation. A few extracts from reports are here given in order to show that suitable action has been taken to inaugurate such a study of the problems of evaporation on the large scale presented by the drying out of the Salton Sea.

Mr. M. O. Leighton, Chief Hydrographer of the U. S. Geological Survey writes as follows:

(A) NOTES ON THE PRACTICAL VALUE OF INVESTIGATIONS OF EVAPORATION.

Great water supplies in the arid regions must in nearly all cases be the result of conservation of flood waters. This makes it necessary that these waters be stored for long periods in reservoirs with an enormous surface exposure. Such conditions are ideal, especially in hot countries, for maximum loss by evaporation. Loss of water in the arid regions is always a serious factor. It may mean a loss of productivity over large areas of country. It, therefore, becomes a practical question, the importance of which can hardly be overestimated.

In planning reservoirs for the conservation of water, the capacity of the reservoir controls its usefulness; that is, a reservoir of a certain capacity will supply water sufficient to irrigate a certain acreage, to provide municipal supply to a certain population, or to guarantee a certain minimum amount of power. In determining these duties it is obviously necessary to take into account the losses arising during storage. Therefore, in designing a water supply system of whatever kind, it is necessary to deduct from the amount of water available for storage a certain percentage resulting from loss by evaporation. This would be simple if there were at hand any reliable method for computing such losses. Attempts have been made, but it is apparent that the factors secured are erroneous. Therefore it is of the utmost importance to all water supply installation to have the rate of evaporation under fixt and variable conditions determined. A few practical illustrations: It has been estimated that the evaporation in southern Arizona is equivalent to about 6 feet per year. Whether or not this is true we do not know. Assuming, however, that the figure is a fair approximation, the amount of water lost from the Roosevelt Reservoir, surface extent, 16,320 acres, will be 97,920 acre-feet, sufficient to irrigate 48,960 acres, assuming a duty of water equivalent to 24 inches per annum. The same computations may be made with respect to all the great reservoirs in the arid West. It will, therefore, be seen that in computing the area to be reclaimed under the Roosevelt Reservoir it was necessary to deduct nearly 50,000 acres from that which might have been reclaimed had it not been for evaporation. The Sweetwater and Otay reservoirs in the San Diego region in southern California have never performed the duty that was expected of them. Indeed, during the greater part of the time since they were constructed they have been empty or only partially filled. The evaporation from these reservoirs is enormous, and it is highly probable that had there been any worthy information concerning the rate of evaporation at these points it would have been appreciated that the drainage areas would not provide for actual use an amount of water equivalent to the storage installation. In other words, the plans would have been entirely changed and a large amount of money would have been saved.

The above constitute two typical instances of the practical importance of determining all the factors connected with evaporation. If the facts were known, the engineering profession would probably change its ideas with reference to economic depth of water stored, and shallow areas within reservoirs at which it is assumed that evaporation may be greatest would be avoided. If the effects of winds were known, ideas with reference to the proper location of reservoirs would probably be changed, and there would be some useful study and experimentation with reference to the effect of windbreaks, etc. In fact, we can only generalize about the matter, even as it is necessary to generalize with reference to the methods of evaporation study. Each reservoir in the west is subject to great loss. We do not know how much, but it is apparent that did we know subsequent work of this character would be more intelligently carried on.

Appendix B of the report of the Conference Board is given in full as follows (see Chart IX):

(B) MEMORANDUM ON THE IMPORTANCE OF THE PROPOSED INVESTIGATION OF EVAPORATION IN THE SALTON BASIN.

Past and future history of the Salton Sea.

Salton Basin, in the extreme southeastern part of California, is a depression below the level of the sea, its lowest point being 287 feet below mean tide. The basin is separated from the Gulf of California by the delta of the Colorado River. In past time the river has flowed alternately to the gulf and to the basin. Four years ago all the water of the river flowed to the Gulf of California, and the basin was dry. A canal made for irrigation purposes, leading water from the river toward the Salton Basin, became enlarged in time of flood and past beyond control, so that after a few months the entire river discharged to the basin. For more than a year it flowed in that direction, and it was finally brought under control only after strenuous effort. The river has now been returned to its former channel and discharges to the Gulf of California, excepting a small portion employed for irrigation in the Imperial Valley—"Imperial Valley" being the name given to that part of the river delta which slopes toward the Salton Basin.

While the river flowed into the Salton Basin it gradually flooded the lower part of the basin so that now there is a lake or sea about 80 feet deep with a surface area of 440 square miles. As important interests are involved, it may be assumed that the river will be restrained from again invading the basin and that the lake which now exists will gradually dry away, its dissipation requiring between ten and fifteen years.

Need for investigation of evaporation.

In the construction of reservoirs, for whatever purpose, it is necessary to make allowance for evaporation in order to determine in advance what will be the available supply of water. In the work of the Reclamation Service the allowance for evaporation is often very large and affects the plans and estimates of cost in important ways. It is always a factor to be considered in estimating the available supply obtainable from a reservoir of known capacity, and is likewise a factor used in determining the height of a dam of greatest storage efficiency. The exposure of an unnecessarily large area behind a dam of too great height may result in excessive wastage of the supply. Moreover, an inadequate allowance for loss by evaporation from the reservoir surface leads to erroneous assumptions concerning the water which can be made available for useful purposes.

Unfortunately the rates of evaporation for different climates are not well known, so that at present it is impossible to make estimates with desirable precision. It is known that the rate of evaporation in any locality depends on certain factors, namely, the temperature of the air and water, the dryness of the air, and the velocity of the wind; but the nature of the law or formula connecting the evaporation with these factors is not known. Various attempts have been made to determine it, but the results are so discordant that little confidence is felt in any of them. It is known also that a formula for evaporation derived from experiments with a small water surface—such as that afforded by a tank, for example—can not be applied directly to the computation of the evaporation from a reservoir or lake, because the larger bodies are differently affected by the wind. As the air moves across a reservoir and gradually becomes charged with moisture its rate of absorption diminishes, and the average rate of evaporation from a broad surface is therefore less than from a small surface. For this reason the formula for evaporation can not be put on a sound basis without taking account of large water surfaces as well as small. Attempts to measure evaporation from lakes and reservoirs have heretofore been hampered by the difficulty of accurately measuring inflow and outflow so as to discriminate the various factors determining changes in the level of the water surface.

Availability of the Salton Sea.

The conditions afforded by the Salton Sea are peculiarly suitable for the investigation of the laws of evaporation. The amount of water flowing into it is small and can readily be measured. The rainfall is nominal in amount. No water flows out of it. The climate is so dry that the total evaporation in a year will probably amount to 6 or 8 feet. It is therefore possible to determine by gaging the actual rate of evaporation, and to make this determination with high precision. By making the gaging continuous, and by making simultaneous observations of the temperature, atmospheric humidity, wind, etc., the relations of evaporation to these several factors can be made out. It is possible, also, by a suitable arrangement of details and by the use of evaporation tanks, to take account of the relation of evaporation to the size of the evaporating surface.

By reason of the dryness of the local climate, the evaporation rate in the Salton Basin is unusually high. Therefore a formula based on observations at this place will have such range as to be available for all cases likely to arise.

It is especially to be noted that the opportunity given by Salton Sea is both temporary and unique. In ten or fifteen years the sea will have disappeared, and in a somewhat shorter period its waters will become so saline that its rate of evaporation will no longer be normal and representative. It is not to be restored if the resources of the engineer can prevent. Moreover, the combination of physical conditions and events by which the sea was created is so peculiar as to warrant the belief that it is not duplicated elsewhere, certainly not within the United States. Unless use is made of the present crisis in the history of the basin, the opportunity will be lost.

(C) ACCOUNT OF THE WORK OF INSPECTION FROM THE REPORT OF THE CONFERENCE BOARD.

In compliance with instructions received, the undersigned, F. H. Bigelow, representing the U. S. Weather Bureau, G. K. Gilbert, representing the U. S. Geological Survey, and C. E. Grunsky, representing the U. S. Reclamation Service, met at Yuma, Ariz., on May 12, 1907, for the purpose of outlining the scope and methods of an investigation of evaporation in connection with the drying out of Salton Sea, Cal. An organization as a Conference Board was effected by electing F. H. Bigelow chairman, and with all members participating the board was in session from day to day at various places in Salton Basin and held a final session at Los Angeles.

It was recognized in advance that in order to determine the law which controls evaporation and thus utilize to the fullest extent the opportunity afforded by the drying out of the lake, the meteorological conditions at and near the lake must be thoroly investigated; and it was early apparent that financial considerations would make it impossible to install and put in operation at once the fully equipped stations required for this purpose. The board, therefore, has given special consideration, first, to the work which should be immediately undertaken with means now at command, and, second, to scope the work as it should be carried out when suitable financial provision shall have been made.

The board confirms the conclusion reached by the earlier conference committee that the Weather Bureau should direct the making of the observations and should have primary charge of working up results.

Both the Geological Survey and the Reclamation Service should cooperate in the work to the extent found practicable from time to time, and both of these bureaus should remain in close touch with the work. For this reason it appears a wise provision to have the scope of the work and the methods of observation past upon from time to time by this conference board, which should be continued indefinitely for this purpose.

It is foreseen that after the observations have been established on a comprehensive basis, they should be continued without interruption for two or three years; whether for a longer period can not be determined until the results of two years' observations become available.

The board desires to express its appreciation of the preliminary work done in connection with this subject by the U. S. Geological Survey, which, upon a first suggestion that such a study should be made, at once ordered an examination by W. F. Martin, whose exploration of the shores of the sea and of the conditions of run-off from the surrounding country greatly simplified our own investigations. The board found it necessary, however, to have personal knowledge of the physical condition of the country surrounding the large body of water, and also to know something of the conditions which led to the formation of the lake, and to understand the present situation at the Colorado River, which, if modified, may affect the accession to the waters of Salton Sea. Consequently an inspection was made of the works which turned the Colorado River back into its proper channel, and of the levees extending some ten miles beyond the lower Mexican heading which is intended to reduce the annual overbank flow toward the west and north.

The board visited the margin of the sea at its southern extremity, and at several points on the east and northeast along the line of the Southern Pacific Railroad, notably at Durmid and at Salton. Inquiry and personal investigation were also made of the suitability of Yuma, Mammoth Tank, Brawley, Mecca, Indio, and Edom as stations for the meteorological observations required in connection with the direct observation of evaporation and with the study of the effect of a large body of water upon the rate of evaporation.

The control of the Colorado River.

The ancient Gulf of California extended about 150 miles farther north than the present Gulf, filling the entire valley between the two mountain ranges on the east and west. The inflowing waters of the Colorado River, carrying much sediment, gradually pushed a wide delta across this arm of the sea, cutting off the northern portion of the basin, and isolating it. The courses of the river on the top of its delta-divide have been uncertain and shifting, so that the water seeks to flow at times to the Salton Basin and at other times to the Gulf, thus spreading the silt over wider areas. The Salton Sea has been subject to drying out and refilling many times, according to the temporary course of the river. The bottom of the Salton sink is 287 feet below sea level, and Volcano Lake on the top of the delta is 30 feet above sea level, so that the gradient of water flow from the river to the basin is very much greater than it is to the Gulf. Therefore, the Salton inflows are very rapid and powerful, tending to cut thru the delta deposits and transport large masses of soil into the lower levels. In the interests of irrigation in the Imperial Valley, in 1891, a small channel was cut from the Colorado River into the bed of the Alamo River; but, this proving to be insufficient, a second heading was made a little below the first heading, both of these being just below Pilot Knob and north of the Mexican boundary line. In 1903-4 a third heading in Mexican territory, four miles from the boundary, was made, but in the summer of 1904 this channel was worn away too much by the Colorado River, which began to pour down in immense volume and to construct for itself a new channel toward the Salton sink. Great destruction was caused along the Alamo and New rivers, and the irrigation interests of the entire Imperial Valley were threatened. The rising waters made it necessary for the Southern Pacific Railroad to move its tracks three times. It is estimated that the fate of 700,000 acres of fine irrigable land in a semi-tropical region, the homes of 12,000 to 15,000 people, and 150 miles of railroad track, all worth $100,000,000 at an undervaluation, were trembling in the balance. Several serious efforts were made in 1906 to turn back the river to its old channel, with apparent success on November 4. Within four weeks after that date the water worked around the end of the dams; but the attack upon the river was renewed again with great vigor, and at the cost of several millions of dollars, on February 11, 1907, the levees were secured, so that in May they seemed to be very strong and capable of withstanding the June floods which would test their stability. A railroad track is laid on the northern levee for 12 to 15 miles below the permanent heading constructed of concrete and with hydraulic gates, and every effort will be made to preserve the levee intact this year as far as constructed. It is proposed to extend this substantial dike across the delta region till it terminates on the foothills of the Cocopah Mountains on the western side. In case this levee holds, the Salton Sea will evaporate in ten or twelve years, contracting in area from 440 square miles, thus giving a succession of lakes of different sizes. It is immediately in contact with irrigated territory on the north side from Mecca to Indio, where are located the "Government Date Farms"; also on the south side, from Brawley to Calexico, there is an irrigation district covering 400 square miles; beyond these semi-arid districts is the pure desert, one station being available at Edom on the north and one at Mammoth Tank on the south. By the courteous cooperation of the officials of the Southern Pacific Railroad, represented by Mr. R. H. Ingraham, the Division Superintendent at Los Angeles, it is proposed to establish desert stations at Edom and Mammoth Tank; irrigation stations at Indio, Mecca and Brawley; and lake stations, one at Salt River, where there is a long trestle bridge crossing an arm of the sea about 40 feet deep, and another on a large raft anchored in the middle of the Salton Sea, as near as practicable to the point of zero-node of oscillation due to the wind action. The prevailing winds are from the northwest or from the southeast, as guided by the large mountain ranges, so that the evaporating atmosphere over the chain of stations will undergo conditions subject to reversals of meteorological values, and thus afford the means to differentiate the terms in the formula of evaporation, which it is designed to procure from the general research. The work of the first year will consist of a preliminary study of evaporation at Reno, Nev., where Professor Bigelow will locate with a small party; in October it is designed to open the chain of stations in the Salton Basin, all working with simple apparatus, intended to give a birds-eye view of the scientific aspects of the problem. During the second year, beginning July, 1908, the complete program will be inaugurated in charge of a physicist in the field, and conducted on the best basis known to science, both as to instruments and thermodynamic theory.

The need for further research into the theory of evaporation in the open air.

OBSERVATIONAL.

There have been several important and extensive researches into evaporation phenomena such as exist over lakes and reservoirs in different climates, wherein attempts have been made to arrive at a general formula to express the results of the observations upon the amount of evaporation, in terms of several simple arguments.

(1) *Russell* (1887–1888):

$$E, \text{ inch/month} = \frac{30.00}{B} [43.88 (e_1 - e_d) + 1.96 e_1],$$

where e_1 is the vapor pressure at the temperature of the wet-bulb thermometer, and e_d the vapor pressure at the dew-point temperature.

(2) *Abbassia* (Egypt):

$$E, \text{ mm./month} = 8.8(e_w - e_d) (1+0.0239 k),$$

where e_w is the vapor pressure at the water-surface temperature, and k is the velocity of the wind in kilometers per hour.

(3) *Fitzgerald* (Boston, 1876–1887):

$$E, \text{inch/day} = 0.3984 (e_w-e_d) (1 + 0.0208 w_1),$$

where w_1 is the wind movement per day.

(4) *Carpenter* (Fort Collins, 1887):

$$E, \text{inch/day} = 0.3868 (e_w-e_d) (1 + 0.0025 w_1).$$

(5) *Stelling* (Russia, 1875, 1882):

$$E, \text{mm/2 hours} = 0.0702 \Sigma (e_w-e_d) + 0.00319 \Sigma(e_w-e_d) w,$$

where $\Sigma (e_w-e_d)$ is the sum of 12 readings made every two hours.

It is seen that all but Russell use the formula known as Dalton's Law, whose form is,

$$E = \frac{dv}{dt} = A (e_w-e_d) (1 + c k), \tag{6}$$

the arguments being the temperatures of the water surface and the dew-point of the atmosphere, together with the movement of the wind. Reducing Abbassia, Fitzgerald, Carpenter, and Stelling to a common form and standard units, in order to give the evaporation in millimeters per hour, using v, the wind velocity in meters per second, we have:

(7) *Abbassia:*

$$E, \text{ mm./hour} = 0.0122 (e_w-e_d) + 0.00029 (e_w-e_d) v.$$

(8) *Fitzgerald:*

$$E, \text{ mm./hour} = 0.0166 (e_w-e_d) + 0.000783 (e_w-e_d) v.$$

(9) *Carpenter:*

$$E, \text{ mm./hour} = 0.0161 (e_w-e_d) + 0.0000895 (e_w-e_d) v.$$

(10) *Stelling:*

$$E, \text{ mm./hour} = 0.0351 (e_w-e_d) + 0.00044 (e_w-e_d) v.$$

An inspection of the constants shows that altho these formulas may represent the local rates of evaporation, the formulas can not be considered sufficiently general to be of use in localities where the constants have not been especially determined. To illustrate the results to be obtained by using these formulas on the same example, we have computed the hourly amounts of evaporation per hour by assuming, in the centigrade system,

$t_w = 23.9$ C.°, $e_w = 22.02$, (by the Smithsonian Tables),
$t_d = 15.6$ C.°, $e_d = 13.17$,
$v = 10$ meters per second. Hence, $e_w - e_d = 8.85$ mm.

Abbassia:

$$E, \text{ mm./hour} = 0.1080 + 0.0257 = 0.1337.$$

Fitzgerald:

$$E, \text{ mm./hour} = 0.1469 + 0.0693 = 0.2162.$$

Carpenter:

$$E, \text{ mm./hour} = 0.1425 + 0.0079 = 0.1504.$$

Stelling:

$$E, \text{ mm./hour} = 0.3106 + 0.0389 = 0.3495.$$

The agreement is so unsatisfactory as to suggest that the formulas have not a comprehensive form, and that the so-called constants determined empirically are in reality variable to a considerable extent.

THEORETICAL.

There are several thermodynamic theories of evaporation, such as are collected in Vol. II of Weinstein's Thermodynamics, 1905, of which Stefan's is the most suggestive. He assumes the very special case of a tube, wherein the vapor pressure is maintained at $e=0$ at the top of the tube, while diffusion is proceeding from the water surface at the distance h below the top. If n is the total number of air and vapor molecules in a thin layer dh at the surface of the water, containing N_1 vapor molecules, and $(n-N_1)$ air molecules, so that N molecules diffuse into air from the water, the velocities being u_1 and u_2, respectively, for vapor and air molecules, we have the equations of steady condition of the thin layer,

(11) $n_1 u_1 = (N_1 - N) \frac{dh}{dt}$, for vapor moving from the water,

(12) $n_2 u_2 = (n - N_1) \frac{dh}{dt}$, for air moving toward the water,

(13) $n_1 u_1 + n_2 u_2 = (n - N) \frac{dh}{dt}$.

The common equation for diffusion is,

$$\frac{\partial u_1}{\partial t} = D \frac{\partial^2 n_1}{\partial x^2}, \tag{14}$$

where D is the coefficient of diffusion, and x is the distance along the central axis of the tube.

Stefan applies this to his assumed tube and its conditions in the form,

$$\frac{\partial u_1}{\partial t} = D \frac{\partial^2 n_1}{\partial x^2} + \frac{N-n}{n} \frac{\partial n_1}{\partial x} \frac{\partial h}{\partial t}, \tag{15}$$

and finds the approximate solution,

$$h^2 = \frac{nD}{2N} \log \frac{n}{n-N_1} \cdot t. \tag{16}$$

Since the densities are $\rho = Nm$, $\rho_1 = nm = \rho_0 \frac{p}{p_0} \frac{T_0}{T}$,

$$h^2 = \tfrac{1}{2} \frac{\rho_0}{\rho} \frac{T_0}{T} \frac{p}{p_0} D \log \frac{p}{p-p_1} . t. \tag{17}$$

This form is so far irreconcilable with Dalton's simple law, that Weinstein remarks that Dalton's Law is entirely unsatisfactory. Therefore we must conclude that a complete research is needed, not only to determine the thermodynamic formulas under general conditions, especially such as prevail in the open, where the diffusion lines are so seriously interfered with and distorted by the movements of the wind. The subject is far too complex to take up at this time, but it may be well to indicate some facts regarding its treatment in general.

The general theory of evaporation.

There are two processes taking place in the case of evaporation, namely, (1) the transformation of water in the liquid state into the same water in the vapor state, and (2) the diffusion of this gaseous vapor into the atmosphere, which already contains a certain quantity of vapor. The first process is confined to a very thin layer adhering to the water surface, and the rapid removal of this film by the wind accelerates diffusion.

The gradients of diffusion are nearly discontinuous at this film, change rapidly in the first few millimeters, and then slowly up to great heights. The wind velocity from the surface up to 10 meters is an important function to be determined; the distribution function under the action of the wind is a very complex and difficult one to determine in the open air over a lake swept by variable wind currents. The limited amounts of the diffusion involve the reasons why natural air is usually saturated to only 80 per cent of its total capacity, or, vice versa, why it is so hard to dry out the last few per cent of vapor from a mixt atmosphere. Then, too, nearly all the difficulties arising from the fact that the constants required in the kinetic and thermodynamic computations are not very accurately known enter this problem with great persistency, so that many intricate physical investigations are suggested as advisable at the outset. In order to illustrate these remarks a little more fully I will extract from my computations some data applicable to the case of the atmosphere with as few remarks as possible on this occasion. Since the Boyle-Gay Lussac Law, $Pv=RT$, is at the basis of the kinetic theory of gases and the thermodynamics of gases, it follows that each of these theories is interconvertible whenever desired in discussions.

I. By converting a certain volume of water, v_2, in cubic centimeters, into vapor at a given temperature, T_1, and pressure, P_1, we get, by Clayperon's formula, the volume v_1, using r_1, the latent heat of vapor, and A, the mechanical equivalent of heat.

$$(18)\qquad v_1 = v_2 + \frac{r_1}{A T_1}\frac{dT_1}{dP_1}\frac{41855000 \times 760}{1013240}.$$

TABLE 1.—*Volume changes of water to vapor at different temperatures.*

t centigrade	0°	10°	20°	30°	100°
T absolute	273	283	293	303	373
r_1 latent heat	606.5	599.4	592.3	585.3	535.7
$\frac{dP_1}{dT_1}$ gradient	0.33	0.61	1.07	1.81	27.20
v_1 volume	211356	109006	59312	33507	1659

One cubic centimeter of water is converted into v_1 cubic centimeters of vapor at the temperature t. If a surface of water is lowered 1 centimeter by evaporation, the volume of vapor, v_1, is to be disposed of by diffusion into and mixture with the dry air, or with air already partly mixt with aqueous vapor. Diffusion in the several strata above the surface, at the heights 1, 2, 3 . . . . . . h centimeters, goes on at very different rates when the air is calm, and this function must be discovered. When these strata are set into commotion by the movements of the wind over the water surface there is added a factor or function for mixture that is of great complexity. The formula for the weight in grams of the water contained in 1 cubic centimeter of air in the state of saturation at the temperature t is given by

$$(19)\qquad \sigma = \sigma_0 \times 0.622\, \frac{T_0}{T}\frac{e_s}{Bn},$$

where $\sigma_0 \times 0.622 = 0.00129305 \times 0.622 = 0.0008043$, $\frac{T_0}{T} = \frac{1}{1+at}$, e_s is the vapor pressure of saturation, and $Bn = 760$ millimeters. For the same temperatures as in Table 1 we have:

TABLE 2.—*Reciprocal relations between the formulas (18) and (19).*

e_s vapor pressure	4.57	9.14	17.36	31.51	760.00
σ density	.000004836	.000009330	.000017116	.000030040	.000588471
$\sigma v_1 = 1$	1.0222	1.0171	1.0152	1.0065	0.9761
R gas constant	3539	3520	3514	3484	3380

It is seen that v_1 derived from Clayperon's formula and σ derived from the Smithsonian Tables are nearly reciprocals, the slight imperfections between these systems, one theoretical and the other experimental, indicating that the exact balance among the numerical quantities has not yet been obtained.

II. To illustrate the kinetic theory of gases in this connection, the following data for several gases have been compiled into a homogeneous system for the standard conditions (see Table 3). Departures from the standard values of pressure, $P = 760$ mm., and temperature, $T = 273°$, must be computed in auxiliary tables, in order to follow along the fluctuating conditions of the atmosphere. Take $\frac{1}{A} = 41852800$,

Pressure, $P = B_n \rho_m g_0 = 76 \times 13.5958 \times 980.6 = 1013235$,
Absolute const. $K = Pm_0/\rho_0 T = 1013235 \times 2.00 / 0.000090 \times 273 = 8248111$.

As to the value of the specific heat at constant pressure c_p and the specific heat at constant volume C_v, their difference $C_p - C_v = R$, and their ratio $C_p/C_v = k$, a collection was made of the measurements of these quantities, as given by many authorities. A mean value of C_p was adopted, and C_v, k were computed by using R as determined by the formula $R = K/m$. Then these values of C_v were reduced to heat units in calories and compared with the values given by laboratory measurements. The agreement was satisfactory for all gases except CO_2, where C_v seems to be too large, that is 0.1720 instead of 0.1666, and k too small, that is 1.2617 instead of 1.3022. Carbonic dioxide is usually anomalous in its action, and the discrepancy is probably due to some peculiarity of its constitution. The measured values were adopted for CO_2. With these values of C_v the coefficient of heat conduction is computed, using Maxwell's constant, 1.667. The diffusion constant is computed for air and aqueous vapor as a pair, with the result, $D = 0.1616$.

III. The next steps in the solution of the diffusion problem are much more complicated, because they involve the evaluation of the differential equations whose integration is possible only in simple particular cases, and then only by the use of a Fourier Series. The mathematical analogy between the flow of heat and the distribution of heat on the one hand, and the flow of evaporation products in stream lines with their equipotential gradient surfaces on the other, seems to be complete. In the case of evaporation the solutions become unusually complex by reason of the action of the wind disturbing the positions of the stream lines and the potential surfaces, in so irregular a manner as to render the usual solutions of the equations under the assigned limiting conditions inapplicable. The equations can probably be modified for practical work as soon as experiment gives some knowledge of the magnitude of the constants involved, and this it will be necessary to learn by actual observations in the field.

For the equipotential surfaces in two dimensions where one end of a tube, with impervious sides, has an evaporating fluid, we have equations of the form,

$$(20)\qquad \frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} = 0,$$

whence

$$(21)\qquad u = \frac{4}{\pi}\left[e^{-y}\sin x + \tfrac{1}{3}e^{-3y}\sin 3x + \tfrac{1}{5}e^{-5y}\sin 5x + \;\ldots\ldots\right].$$

For the flow of evaporation from a surface, as from the ocean to the air, where the flow is at right-angles to the surface, we have,

$$(22)\qquad du = D\frac{d^2u}{dx^2}.$$

$$(23)\qquad u = \frac{1}{\sqrt{\pi}}\int_{-\infty}^{\infty} f\,(x + 2a\sqrt{t}\,.\,\beta)\,e^{-\beta^2}\,d\beta,$$

where

$$\beta = \frac{\lambda - x}{2a\sqrt{t}}, \text{ and } \lambda = (x + 2\,a\sqrt{t}\,.\,\beta).$$

TABLE 3.—*Formulas and constants from the kinetic theory of gases.*

Formulas.	Air.	Aqueous vapor. (H_2O)	O_2	N_2	CO	CO_2	H_2
m = molecular weight	28.735	17.88	31.76	28.02	27.88	43.76	2.00
$\rho = Pm/TK.$ = density	.00129305	.0008046	.0014292	.0012609	.0012546	.0019691	.0000900
$R = K/m.$ = constant	2870330	4613000	2597000	2943600	2958430	1884830	41240000
Check $Pv = RT.$	This check is complete for each gas.			....	....	....	....
$n = \rho/m = B/KT = 2hP.$	.000046	Constant for the series.		....	....	....	....
$q^2 = 3P/\rho$; whence the velocity q =	48486	61466	46119	49100	49223	39290	183779
$\gamma^2 = \frac{8}{3\pi}q^2$; whence the velocity γ =	44669	56629	42489	45237	45350	36198	169320
$h = 3/2mq^2.$	Is a constant parameter. 0.000000000022204				....	....	....
η = coefficient of friction	.000172	.000097	.000191	.000167	.000167	.000145	.000084
$l_{max} = \eta/0.30967\ mn\gamma.$	.00000962	.00000688	.00001018	.00000945	.00000948	.00000657	.00001780
$\nu = \gamma/l$, number of collisions	4645×10^6	8237×10^6	4175×10^6	4784×10^6	4784×10^6	5510×10^6	9512×10^6
$Q = 1/4\sqrt{2}\ l$, square surface	18383	25714	17364	18696	18650	26910	9931
$\bar{v}$ = coefficient of contraction	.00190	.00282	.00182	.00219	.00186	.00293	.00203
$s = 6\sqrt{2}\ l\ v$, diameter	155×10^{-9}	165×10^{-9}	157×10^{-9}	176×10^{-9}	186×10^{-9}	163×10^{-9}	306×10^{-9}
$n = 6\ v/\pi\ s^3$, number	97×10^{16}	121×10^{16}	89×10^{16}	77×10^{16}	69×10^{16}	128×10^{16}	13×10^{16}
$l_{max}\ .\ \sqrt{2}\ \pi\ s^2 n = 1$. path	This check is complete for each gas.			....	....	....	....
$L = 1.667\ \eta\ C_0$ = coeff. of conduction.	484×10^{-7}	582×10^{-7}	496×10^{-7}	483×10^{-7}	484×10^{-7}	403×10^{-7}	3392×10^{-7}
D = coefficient of diffusion	$\overbrace{0.1616}$		....	....	....	....	....
C_p = specific heat at constant p (In C. G. S. units)	9935000	19813200	9115500	10203500	10232900	9082000	142633333
C_v = specific heat at constant v (In C. G. S. units)	7065000	15196800	6516430	7261333	7274000	7198667	101390700
$R = K/m = C_p - C_v$ (In C. G. S. units)	2870000	4616400	2599070	2942167	2958900	1883333	41242633
$k = C_p/C_v$	1.40625	1.3038	1.3989	1.4052	1.4068	1.2617	1.4067
C_p = specific heat at constant p (In calories)	0.2374	0.4734	0.2178	0.2438	0.2445	0.2170	3.4080
C_v = specific heat at constant v (In calories)	0.1688	0.3631	0.1557	0.1735	0.1738	0.1720	2.4276
$R = K/m = C_p - C_v$ (In calories)	0.0686	0.1103	0.0621	0.0703	0.0707	0.0450	0.9854
$k = C_p/C_v$	1.4063	1.3038	1.3989	1.4052	1.4068	1.2617	1.4067
C_v by experiment						0.1666	
k by experiment						1.3022	

In case there is leakage to the sides an additional term is required, for example, to allow for the wind effect, of the form,

$$(24)\qquad \frac{du}{dt} = D\,\frac{d^2u}{dx^2} - b^2 u.$$

$$(25)\qquad u = \frac{e^{-b^2t}}{\sqrt{\pi}}\int_{-\infty}^{\infty} f\,(x + 2a\sqrt{t}\,.\,\beta)\,e^{-\beta^2}\,d\beta.$$

If there is a restriction to the flow, in the nature of a conductivity of heat, of which there are many evidences in evaporation, we have a second differential equation to incorporate with the first, something like the following:

$$(26)\qquad \frac{du}{dx} + L\,(u - \theta) = 0,$$

where L is the coefficient of conduction, and θ the temperature of the air in the neighborhood of the water surface.

The preliminary study at Reno, Nev.

It is with the hope of securing a more intelligent view of the problem that some preliminary observations are to be undertaken in July, August, and September, 1907, at Reno, Nev., by means of which the program for the Salton Basin can be suitably prepared for beginning that work in October. The meteorological tables show that in summer the Reno district, to the east of the Sierra Nevada Mountains, is very favorable for excessive evaporation, without the discomfort of abnormally high summer temperatures, such as occur in the Salton Basin. This can be seen by a few extracts collected in Table 4.

TABLE 4.—*Comparison of the meteorological conditions near the Salton Sink, with those in western Nevada.*

(Reno, Nev., is 4533 feet above sea level.)

MEAN MAXIMUM TEMPERATURE.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	°	°	°	°	°	°	°	°	°	°	°	°
Yuma	66	72	78	85	93	101	106	104	100	87	76	68
Mammoth	71	78	81	82	92	107	110	108	101	92	81	75
Indio	......	76	77	106	105	110	113	108	101	90	......	......
Carson City (Reno.)	44	48	53	61	67	76	84	84	75	65	56	46

MEAN MINIMUM TEMPERATURE.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Yuma	42	46	50	55	61	68	77	77	70	58	49	44
Mammoth	39	47	48	48	50	64	74	78	67	62	48	46
Indio	......	45	52	49	56	81	81	79	70	67	......	......
Carson City (Reno.)	22	25	30	35	41	46	52	50	44	35	28	23

HIGHEST TEMPERATURE.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Yuma	81	91	100	107	112	117	118	115	113	108	92	83
Mammoth	88	87	92	98	108	118	119	124	113	108	97	88
Indio	83	90	91	110	113	116	125	116	112	109	98	81
Carson City (Reno.)	63	68	74	82	88	93	100	100	92	85	74	67

TABLE 4.—*Comparison of the meteorological conditions, etc.*,—Continued.

LOWEST TEMPERATURE.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	°	°	°	°	°	°	°	°	°	°	°	°
Yuma	22	25	31	38	44	52	61	60	50	41	31	24
Mammoth .:	27	38	40	32	40	52	60	52	52	53	28	25
Indio........	23	38	39	42	43	62	69	67	48	40	28	20
Carson City (Reno.)	−22	−14	10	16	22	27	35	34	18	17	7	− 7

MEAN PRECIPITATION.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Yuma	0.40	0.50	0.30	0.10	T.	T.	0.10	0.30	0.10	0.20	0.30	0.40
Mammoth...	0.00	1.40	T.	1.40	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.30
Indio.......	0.30	1.20	1.45	0.20	0.00	0.00	0.00	0.50	0.00	0.00	0.75	1.00
Carson City (Reno.)	2.56	1.49	1.33	0.87	0.61	0.43	0.17	0.13	0.28	0.41	1.50	2.19

RELATIVE HUMIDITY AT CARSON CITY.

75th meridian time.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	%	%	%	%	%	%	%	%	%	%	%	%
8 a. m......	80	81	77	71	70	60	56	61	63	71	75	74
8 p. m......	65	71	56	35	41	29	26	30	31	40	55	50

The expedition to Reno, Nev., is being furnished with some improved pieces of apparatus, constructed by the cooperation and devices of Prof. C. F. Marvin, U. S. Weather Bureau, and embodying some suggestions furnished by Mr. Lyman T. Briggs, U. S. Department of Agriculture, and Mr. Edgar Buckingham, Bureau of Standards. These include a measuring micrometer for differential changes in the level of a water surface, an electrical device for maintaining a fixt surface level and measuring the cubic contents of evaporated water, an improved Piche evaporimeter, an anemometer transformed for reading wind velocities in kilometers per hour instead of miles per hour. The evaporating pans and the auxiliary contrivances, such as towers for the equipotential surfaces, tubes for the Stefan formula, and so on, will be constructed at Reno.

Prof. F. H. Bigelow and Mr. H. L. Heiskell go to Reno from Washington, D. C, and will be assisted there by Mr. Harry O. Geren, Section Director, and such further assistants as may be found necessary in reading the thermometers and other pieces of apparatus.

TORNADO AT PARKERSBURG, W. VA.

[Compiled from reports furnished by H. C. Howe, Section Director.]

On the afternoon of Monday, July 22, 1907, a small tornado past over Belpre, Ohio, and Parkersburg, W. Va., two places situated directly across the Ohio River from each other. The windstorm struck Parkersburg at 5:26 p. m., seventy-fifth meridian time, and lasted about three minutes. It came very suddenly and was accompanied by a loud roaring noise. Observers along the river front or at vantage points state that a funnel-shaped cloud, dark gray in color, suddenly shot down from the black clouds overhanging the city, and that the small end of this cloud traveled very near the ground and rotated rapidly. Lightning accompanied the storm, but no vivid flashes were seen. The rainfall was light and no hail was observed.

The storm moved from the northwest to the southeast. Its track could be traced for about one and one-fourth miles, but the greatest width was only about three hundred feet. The southern limit of the storm past two blocks north of the local office of the Weather Bureau in Parkersburg. By the meteorograph record at the office the wind from 5:27 to 5:28 p. m. blew at the rate of 54 miles per hour, but for a 5-minute interval the mean velocity was only 39 miles per hour; the direction was northwest, tho previous to the storm it had been southwest. The pressure, as shown by the barograph, rose suddenly one-tenth of an inch, from 29.85 to 29.95 inches (sea-level).[1] The temperature at 4:30 p. m. was 92°; at about 5:25, 90°; but at 6:00 p. m. it had fallen to 67°. The recorded precipitation amounted to 0.24 inch.

In addition to the statements of observers that the cloud had a whirling motion much may be judged as to the character of the storm from a study of the débris. Nearly all the trees and tops of trees fell toward the north or northeast, and one roof that was removed was thrown toward the north. Windows were broken on the north sides of buildings. One tree standing near the east side of a house was broken down and another tree was apparently twisted off. In Belpre a small house, about forty feet long, sixteen feet wide, and a story and a half high, was blown from its foundation, which consisted of brick piers rising about three feet above the ground. The house was moved about fifty feet in a northeast direction, turned nearly one-quarter round, and completely wrecked. An outbuilding which had stood about forty feet northwest of the house was blown some distance in a nearly opposite direction (southwest).

No lives were lost, but two persons were slightly injured in the wrecking of the house at Belpre. Several smokestacks and roofs were blown off their buildings. Some trees were destroyed by being uprooted or broken off near the ground, and many other tree tops were damaged. Considerable damage was done to telephone wires, but the total pecuniary loss from the storm is estimated at only $5000.

AUSTRALIAN CLIMATOLOGY.

Pending the reorganization of the federal department of meteorology for all Australia the individual state governments still continue their meteorological publications, and we recently received from the meteorological department of the Sydney Observatory several sets of charts illustrating the general characteristics of the meteorology of this continent. Among these charts we note the following:

(1) The weather chart published daily in the Daily Telegraph at Sydney. A few special separate prints of these important charts are struck off for distribution, and they afford the only basis as yet available for meteorologists to study the movements of highs and lows in that region. The highs approach Australia from the southwest and move eastward or northeastward toward the equator. The lows approach from the northwest or west and move eastward or southeastward, that is, away from the equator. The descending air of the highs gives the interior of tropical Australia its characteristic clear, hot, dry, weather, analogous to that of the tropical deserts of Africa, Arabia, Syria, northern India, New Mexico, Arizona, Texas, Peru, Chili, and the California Peninsula. The Australian Continent does not extend far enough south to allow antarctic highs and blizzards to reach its southern latitudes, analogous to those that descend from latitude 60° north into the interior of the United States of America. If such exist they are probably dissipated by the influence of the southern oceans. This great ocean surface not only mollifies the low temperatures of the highs, but by its smoothness allows the formation and maintenance of the steady stream of strong west winds between latitudes 40° and 55° south. These winds are in fact the mechanical representatives of the westerly winds that precede our American highs. The alternations of wind and calm that attend our highs are feebly represented in the Antarctic region, where the wind is more steady and calms are unknown, because of the steady supply of descending air. In forecasting the weather, as is done daily from these Australian maps, one must bear in mind this tendency of highs and lows to be rapidly converted into a long

[1] The rise in station pressure was from 29.20 to 29.30, the station barometer at Parkersburg being 638 feet above sea level.